DARPA/NMS BAA 00-18
AGREEMENT NO. F30602- 00-2- 0556

MEASUREMENT-BASED HYBRID FLUID-FLOW MODELS FOR FAST MULTI-SCALE SIMULATION

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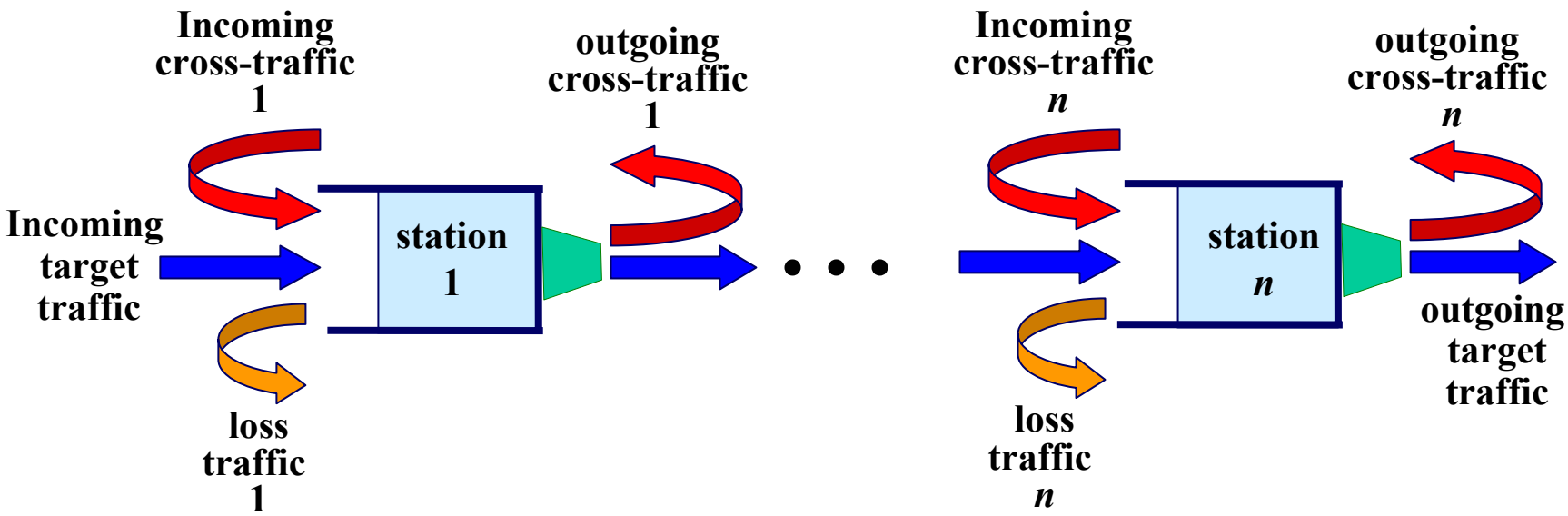
PROJECT GOALS

- **PROBLEM: Emerging high-speed packet-based telecommunications networks are hard to analyze**
  - analytical models of complex networks are intractable
  - simulation of complex networks is either infeasible, or takes forever to complete
- **OBSERVATION: Background (Cross traffic) streams can be aggregated**
  - packet simulations do not scale under aggregation
    - simulator workload is the number of packets, which grows additively in the aggregation level…
  - fluid simulations scale well under aggregation
    - simulator load is the number of rate changes, which is constant in the aggregation level!)

THE GENERIC FG/BG NETWORK MODEL



- **The generic FG/BG (Foreground/Background) network model is a useful class of tandem or feed-forward networks**
  - **foreground streams are target traffic simulated accurately as packets**
  - **background streams are cross-traffic simulated approximately as fluid**

PROJECT GOALS (Cont.)

- **SOLUTION GOALS: Develop a new modeling and simulation methodologies and software**
  - **formulate fluid-flow analytical and simulation models**
  - **hybrid simulation paradigm that combines traditional discrete flows (packets) with continuous ones (fluid)**
  - **implement a "general-purpose" fluid flow simulator based on the hybrid simulation paradigm**
  - **integration with detailed packet-level simulators**
    - **ns2**
    - **GATECH's pdns (parallel distributed ns)**

PROGRESS SINCE LAST REVIEW

- **Design and implementation of HNS (Hybrid Network Simulator)**
  - ***already completed*** **coding and testing of network layer for hybrid model specification, and transport layer for pushing fluid through hybrid network**
  - ***already completed*** **coding and testing of statistics layer (with graphics)**
  - ***newly completed*** **design and implementation of UDP and ATM (both packet or fluid approximation) and TCP (packet)**
  - ***in progress:*** **design and implementation of fluid approximation of TCP**
- **Collaboration with Georgia Tech (Richard Fujimoto and George Riley)**
  - ***already completed:*** **integration of pdns with HNS to combine**
    - **accuracy of packet flows**
    - **efficiency of fluid flows**
  - ***in progress:*** **comparison of ns2 with hybrid of pdns/HNS**

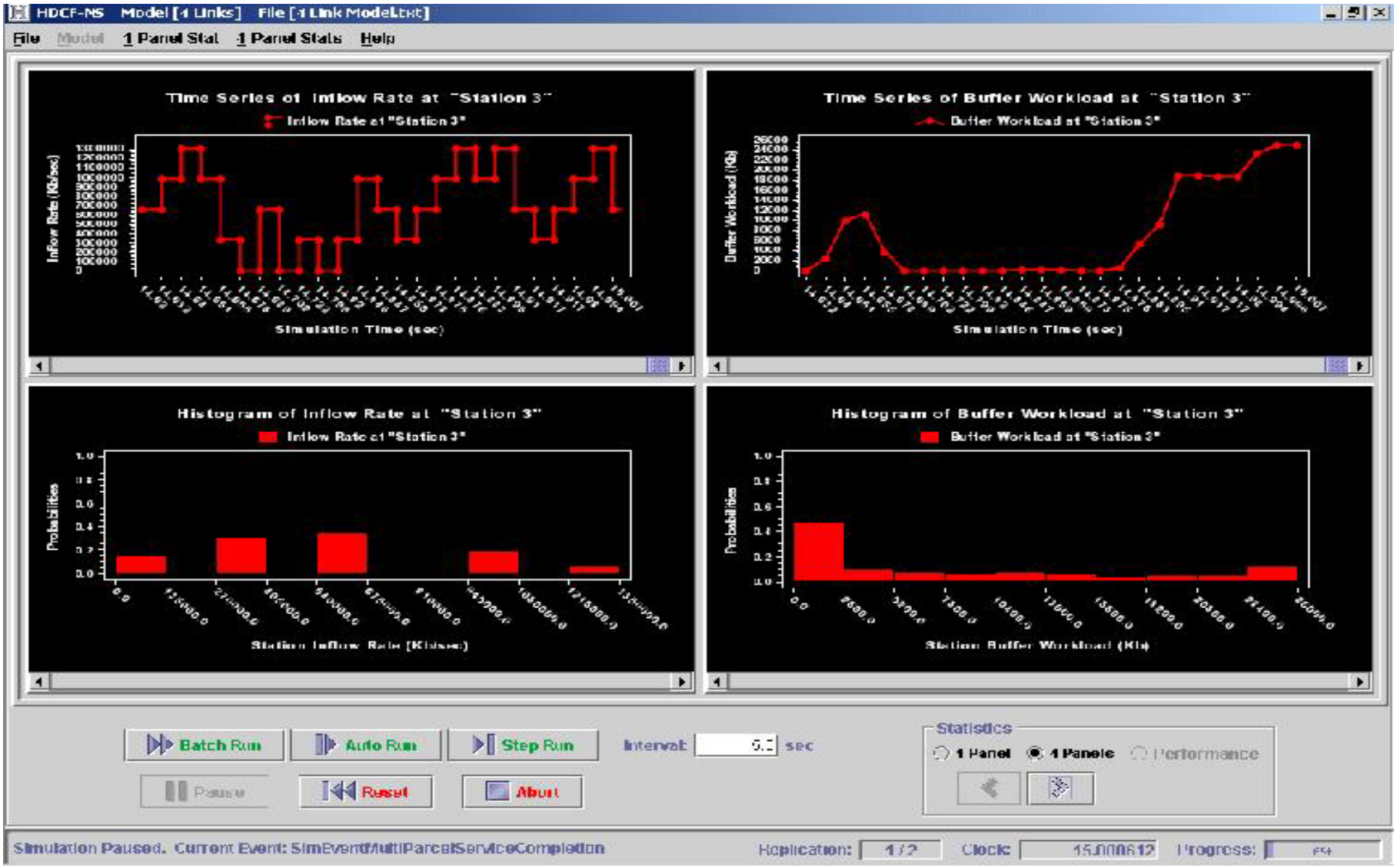
HNS ARCHITECTURE

- **Network layer**
  - stations and sources
  - messages and transactions
- **Transport layer**
  - fluid parcels and multiparcels to keep track of "historical" arrival rates
  - parceling management scheme of fluid
- **Statistics layer**
  - station and message statistics
- **Protocol layer**
  - associated with sources to approximate various telecom protocols (ATM, TCP, etc.)
- **Management / control layer**
  - extensible portion of simulator
  - implements various management / control schemes

HNS WORLDVIEW

- **Hybrid transaction (message) population**
  - **both discrete transactions (packets) and continuous transactions (fluid)**
  - **transactions arrive at stations according to an arrival process, and have a fluid workload (possibly infinite), itinerary, priority and protocol**
  - **transactions traverse the network according to their itinerary and exit or drain at sinks**
  - **transactions only differ in the way their workload is served and routed**
- **Network of connected nodes or links**
  - **feed-forward topology for fluid flows**
  - **arbitrary topology for packet flows**
  - **allocated or shared buffers (possibly of 0 capacity)**
  - **allocated or shared servers**

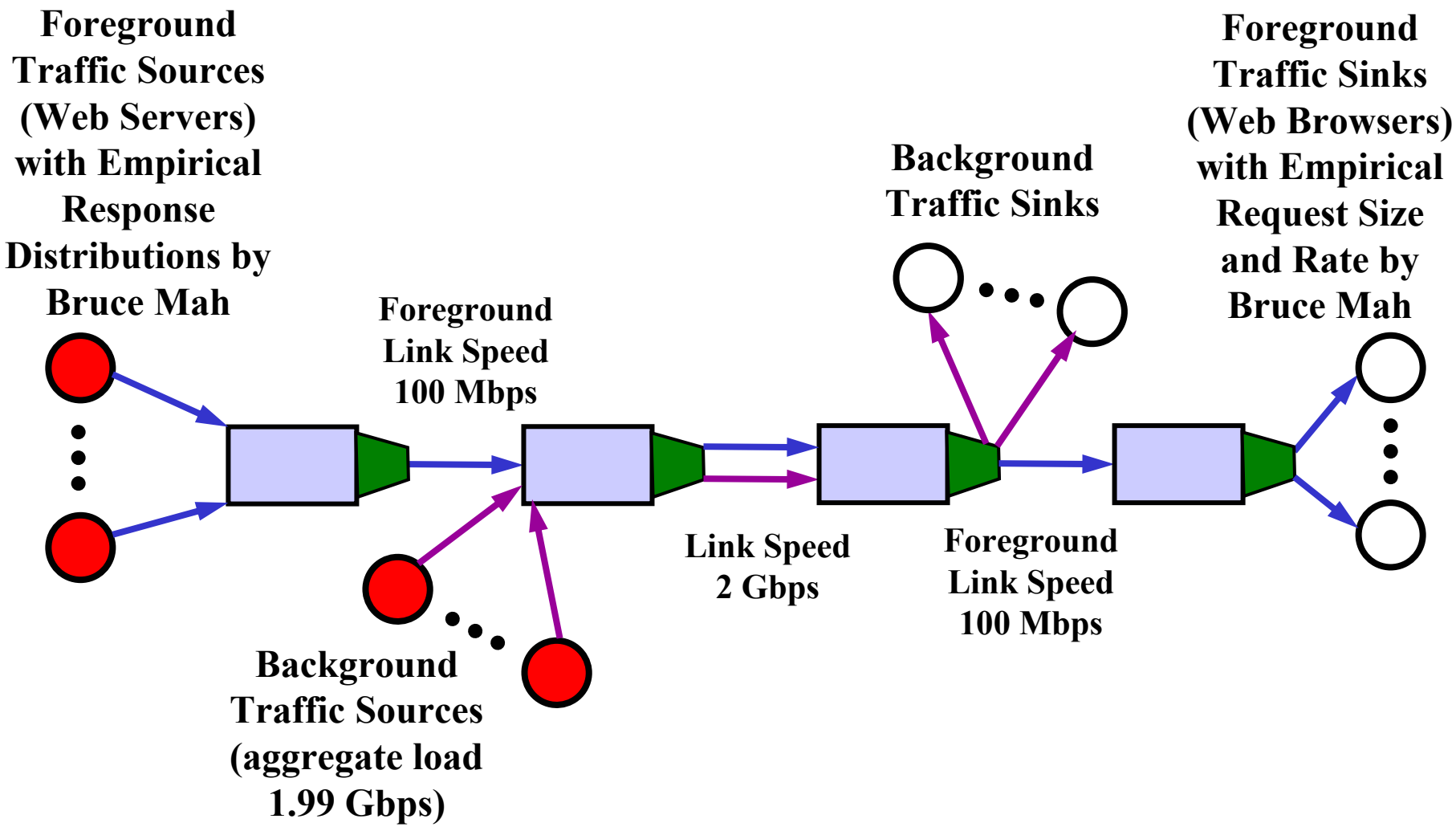
HNS SCREENSHOT



COLLABORATION WITH GEORGIA TECH

- **Motivation: combine strengths of**
  - detailed packet-level simulation capabilities of ns2
  - distributed parallelism capabilities of pdns
  - fast fluid-flow simulation capabilities of HNS
- **Integration effort**
  - integrate HNS via the GATECH backplane and pdns
  - integrate GATECH backplane into HNS
- **Experimenting with FG/BG (Foreground / Background) traffic models (also called Target Traffic / Cross Traffic models)**
  - hybrid model combining detailed packet-level model of target (FG) traffic with fast approximate fluid-flow model of cross (BG) traffic
  - good speedup was observed compared to pure packet model

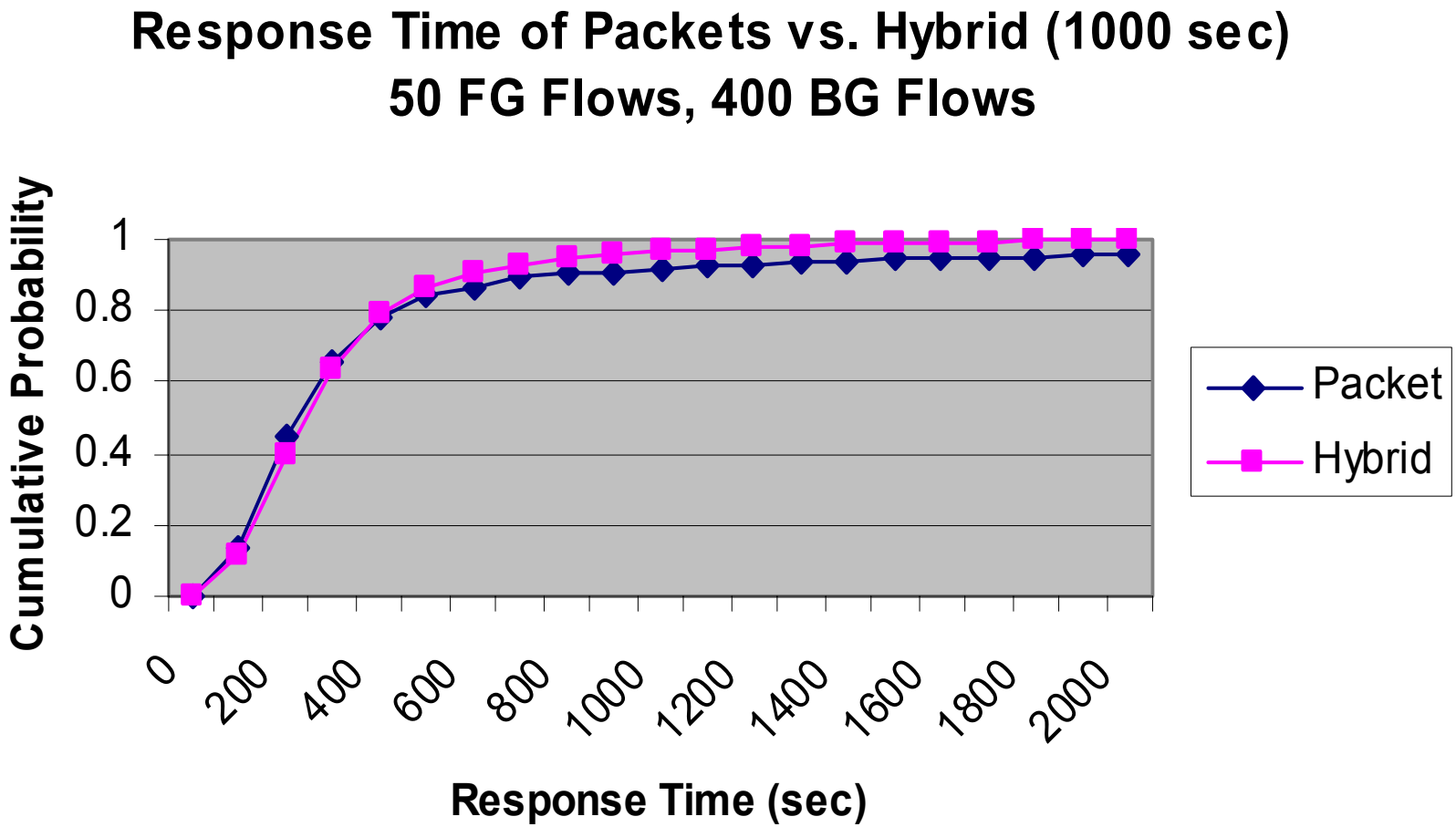
EXAMPLE: WEB BROWSING MODEL



EXPERIMENT RESULTS

- **Speedup for different experiments:**
  - **50 fg and 400 bg → speedup of 3.16**
  - **50 fg and 200 bg → speedup of 10.27**
  - **50 fg and 100 bg → speedup of 40.76**
  - **50 fg and 50 bg → speedup of 137.6**
  - **50 fg and 10 bg → speedup of 242.9**

EXPERIMENT RESULTS (Cont.)



EXPERIMENT CONCLUSIONS

- **Results are very encouraging**
  - fluid-flow model simulations can dramatically speed up packet-based simulations and reduce storage
  - execution speedup for fluid streams is proportional to link speeds
  - memory savings increase with buffer occupancies
  - accuracy is robust in the aggregation level
  - thus, aggregation of fluid streams is a key means for increasing simulation efficiency without reducing accuracy
- **Future work**
  - larger, more complicated hybrid models
  - aggregation techniques for background fluid streams
  - incorporate additional protocols (e.g., fluid TCP)
  - simulator code optimization for further speedup gains